# 800 Gbps Transmission over 8-core MM-MCF for Short Reach Datacom Interconnects

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## Abstract

We demonstrated the feasibility of 8-core MM-MCF to support 800 Gbps transmission over distance suitable for short reach datacom applications using PAM4 and WDM developed for IEEE P802.3cm PMD.

**Keywords:** 400 Gb/s; 400GBASE-SR4.2; Datacenter; Datacom; Multicore MMF; PAM4; 4-level Pulse Amplitude Modulation; Short Wavelength Division Multiplexing

## 1. Introduction

IEEE P802.3cm specified 400GBASE-SR4.2 Physical Medium Dependent (PMD) for short reach applications in data center. Traditional 50/125 µm multimode fiber and MPO cable (OM3, OM4 and OM5) are the physical transmission medium [1]. Spatial division multiplexing (SDM) attracts interest to reduce the footprint and increase cooling efficiency for speed beyond 400 Gbps in data transmission [2,3], particularly for high performance computing where heat dissipation is critical.

Transmission of 400 Gbps signals over an 8-core multimode multicore fiber (MM-MCF) up to 32 m hybrid link was achieved using a 400GBASE-SR4.2 transceiver [4]. The experiment was repeated to study the margin of transmitting 400GBASE-SR4.2 signals over the 32 m hybrid MCF and OM4 link. We further demonstrated a live transmission of aggregated 800 Gbps over the 8-core MM-MCF using two 400GBASE-SR4.2 transceivers simultaneously. We also succeeded in transmitting 100 Gbps per lane using more concatenated cores up to 60 m of a hybrid MCF/OM4 link. The longer reaches were realized by looping back optical signals into different cores of the same MM-MCF. Loop-back configuration demonstrated robustness to added loss and potential crosstalk of multiple splices and fan-in/fan-out (FIFO) transmission.

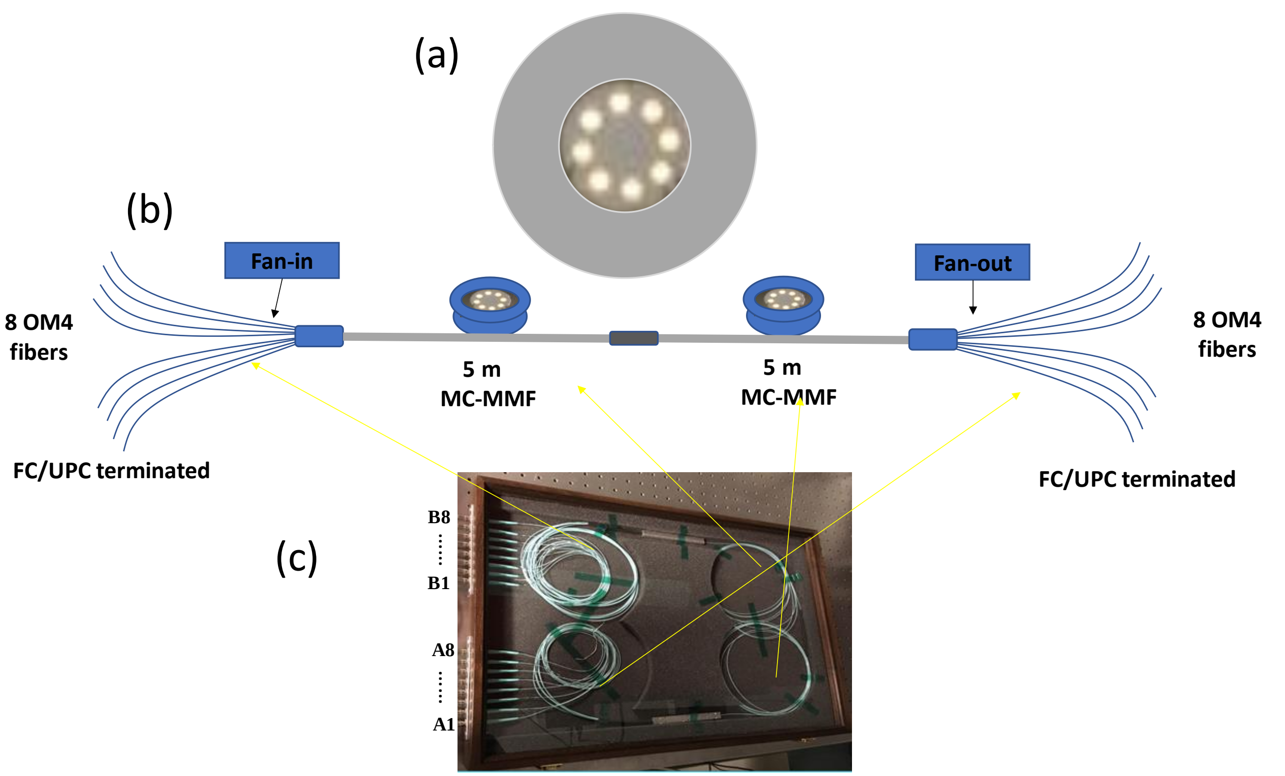


**Figure 1. (a) Cross view of the 8-core MC-MMF. (b) Schematic of the 8-core MC-MMF assembly. (c) Image of the 8-core MM-MCF assembly (inside the wooden box).**

| | VCSEL # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| **Transceiver A** | $\lambda c$ (nm) | 855.5 | 855.5 | 855.4 | 855.4 | 911.1 | 911.1 | 911.0 | 911.0 |
| | RMS (nm) | 0.34 | 0.32 | 0.31 | 0.31 | 0.49 | 0.49 | 0.48 | 0.46 |
| **Transceiver B** | $\lambda c$ (nm) | 858.3 | 858.3 | 858.3 | 858.3 | 910.4 | 910.5 | 910.5 | 910.5 |
| | RMS (nm) | 0.39 | 0.29 | 0.32 | 0.32 | 0.51 | 0.45 | 0.45 | 0.48 |

**Table 1. Transmitter characteristics.**

## 2. Description of the 8-core MM-MCF Assembly

The 8-core MC-MMF (Figure 1a) has eight graded-index Ge-doped cores of 26 µm in diameter and Numerical Aperture (NA) = 0.3 each. The pitch between adjacent core is 41.6 µm. The glass outer diameter is 165 µm and the fiber outer diameter is 300 µm. As shown in Figure 1b&c, an eight 50/125 µm MMFs fan-in (denoted as port A1 to A8) and fan-out (denoted as port B1 to B8) combiner were spliced to both ends of the 8-core MM-MCF to form an assembly. One end of the eight 50/125 µm MMFs was terminated with FC/UPC connector each. The other end of the eight 50/125 µm MMFs were taped down to 26 µm in diameter each and combined into one fiber to splice to the 8-core MM-MCF. The end-to-end length of the MM-MCF assembly was 14 m including two 5 m MCF sections spliced together and 2 m 50/125 µm MMFs in fan-in/fan-out each.

## 3. System Transmission over the 8-core MM-MCF

### 3.1 800 Gbps Transmission over the 8-core MM-MCF using Two 400G-SR4.2 Modules

#### *3.1.1 Experimental Setup*

800 Gbps (2 × 400 GE or 2 × 425 Gbps counting payload) layer 2/3 full ethernet traffic was generated by a Viavi 800G Optical Network Tester (ONT-804D) and loaded into two 400GBASE-SR4.2 FOIT alpha transceivers in QSFP-DD form factor (denoted as A & B). Center wavelength and RMS spectral width of the two transceivers are shown in Table 1. Eight parallel lanes of 50 Gbps PAM4 optical signals at 850 and 910 nm of the two transceivers were transmitting on the eight cores of the MM-MCF assembly bi-directionally. Eight out of 16 lanes of a 1-meter MPO12/16 jumper and 1-meter MPO16 breakout jumper interfaced between transceiver A (or B) and port A/B1-4 (or port A/B5-8) of the FIFO of the 8-core MM-MCF (Figure 2 top). The end-to-end length of the optical link was 18 m where 10 m was in 8-core MM-MCF, 4 m in the 50/125 µm MMF of FITO and 4 m in the OM4 of MPO jumper/breakout assembly.

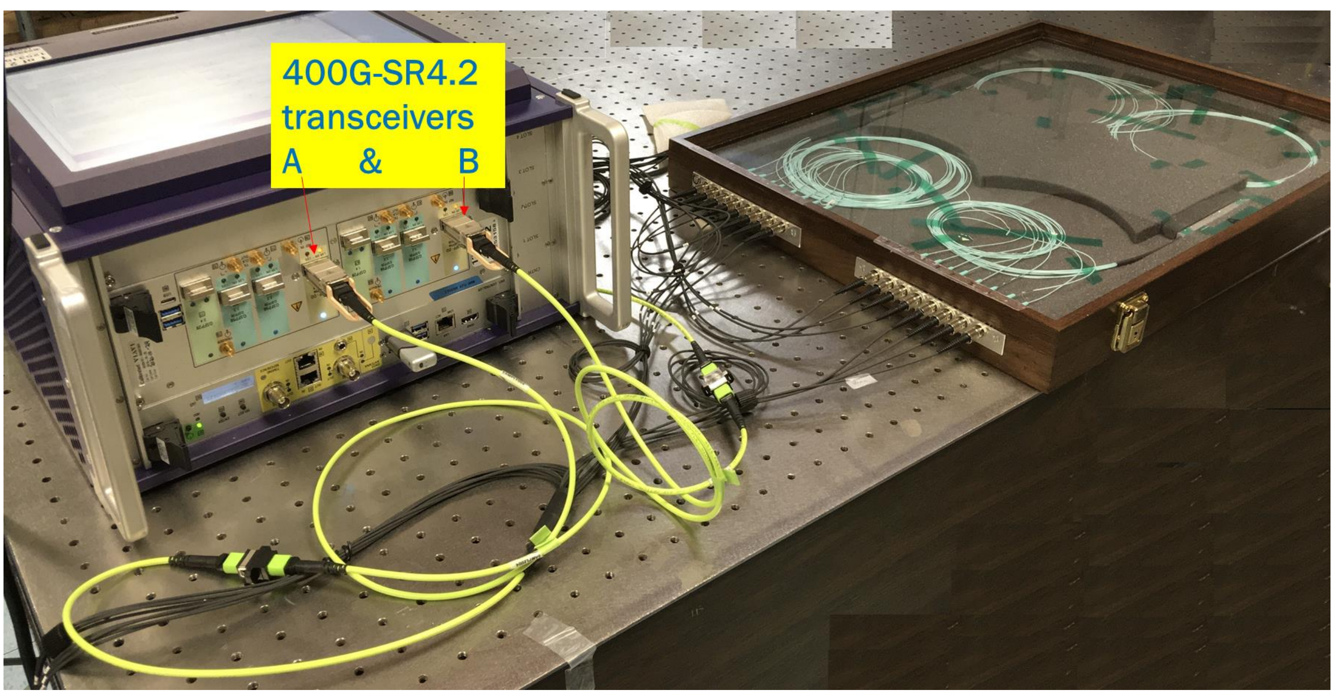


**Figure 2. Image of the 800 Gbps transmission setup over the 8-core MM-MCF using 400G-SR4.2 transceiver module A and B.**

| | bk2bk (module A) | 18 m module A | 18 m module B | 32 m module A | 60 m module A |
|---|---|---|---|---|---|
| No.of Symbols | % | % | % | % | % |
| 1 | 99.880112 | 99.65796700 | 99.87891400 | 99.86286900 | 98.31559000 |
| 2 | 0.119594 | 0.34090000 | 0.11970700 | 0.13672300 | 1.66061900 |
| 3 | 0.000285 | 0.00113200 | 0.00133200 | 0.00039600 | 0.02345800 |
| 4 | 0.000003 | 0.00000500 | 0.00003800 | 0.00000700 | 0.00032200 |
| 5 | 0 | 0.00000006 | 0.00000200 | 0.00000100 | 0.00000500 |
| 6 | 0 | 0 | 0.00000035 | 0.00000017 | 0.00000018 |
| 7 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 | 0 |
| uncorrected error | 0 | 0 | 0 | 0 | 0 |

**Table 2. Receiver PCS layer FEC error statistics for bk2bk, 18 m link, 32 m link, and 60 m link described in section 3.1, 3.2 and 3.3, respectively.**

### *3.1.2 Receiver QoS*

Each core carried 100 Gbps signals resulting in 800 Gbps aggregated live signals on a single 8-core MCF. 100% of the two 400GE ethernet traffic bandwidth was utilized. MAC layer Receiver Quality-of-Service (Rx QoS) showed error/loss free after more than 20 hours of continuous transmission of 800 Gbps PAM4/WDM signals over the 18 m hybrid OM4 and 8-core MM-MCF link. No uncorrectable bits/symbols/words error or frame loss were detected. As shown in column 3 and 4 of Table 2, 9 or 10 out of the 16 FEC symbols didn't even show any correctable pre-FEC error. The pre-FEC bit error ratios (BER) after 18 m OM4/MCF link were $1.9 \times 10^{-8}$ and $8.7 \times 10^{-7}$ using the transceiver A and B, respectively, slightly worse or comparable to the $3.8 \times 10^{-8}$ of the back to back link and 3 to 4 orders better than the FEC threshold of $2.4 \times 10^{-4}$. The system margin estimated by sweeping a variable optical attenuator (VOA) inserted at each output port of the MM-MCF assembly was between 5.8 and 7.4 dB, indicating the stability of the 800 Gbps transmission.

### *3.1.3 Inter-core Crosstalk and Attenuation*

The maximum/minimum inter-core crosstalk of the MM-MCF assembly was -30.6 dB / -39.0 dB at 910 nm and -30.2 dB / -41.3 dB at 850 nm using four VCSELs of the transceiver A and -29.7 dB / -40.9 dB at 910 nm and -31.1 dB / -41.2dB at 850 nm using four VCSELs of the transceiver B. The attenuation of the 14 m MM-MCF assembly was between 0.97 and 2.88 dB using the 8 VCSELs of the two 400GBASE-SR4.2 transceivers each.

## 3.2 Margin of 400 Gbps Transmission over 32 meters of Hybrid OM4 / 8-core MM-MCF Link

In ref [4], we looped the 400 GE PAM4/WDM optical signals from 4 cores into the other 4 cores of the 8-core MM-MCF so that all eight cores were active simultaneously using one 400GBASE-SR4.2 transceiver. Error free transmission was achieved, and we argued that it indeed indicated the feasibility of the 8-core MM-MCF supporting 800 Gbps transmission up to 32 m. The experiment in ref [4] was successfully reproduced using the 400GBASE-SR4.2 transceiver A. The end-to-end link attenuations were between 2.8 to 3.4 dB using the eight VCSELs of the 400G transceiver. The pre-FEC BER was $2.5 \times 10^{-7}$, three orders of magnitude better than the KP4 FEC threshold. We further measured the maximum allowed received power by adding an VOA at the receiving port of each lane. The system margin estimated was between 2.8 and 4.5 dB indicating the robustness of the transmission.

## 3.3 Extension to 60 Meters of Hybrid OM4 / 8-core MM-MCF Link

Encouraged by the margin of the 400 GE experiment over 32 m transmission, we were driven to explore the maximum reach supportable by the MM-MCF assembly. One lane of the 4 × 100 GE PAM4/WDM optical signals (50 Gbps at 850 nm and 50 Gbps at 910 nm transmitting bi-directionally) were transmitted over 60 meters hybrid OM4/MM-MCF by concatenating the output ports to input ports of the MM-MCF three times. The details of the link design and how the optical signals flowed from the transmitter to the receiver at 850 nm are shown in Figure 3 and its inset image. Optical signals at 910 nm were transmitting in the opposite direction. The end-to-end link length was 60 meters including 40 m in the concatenated cores

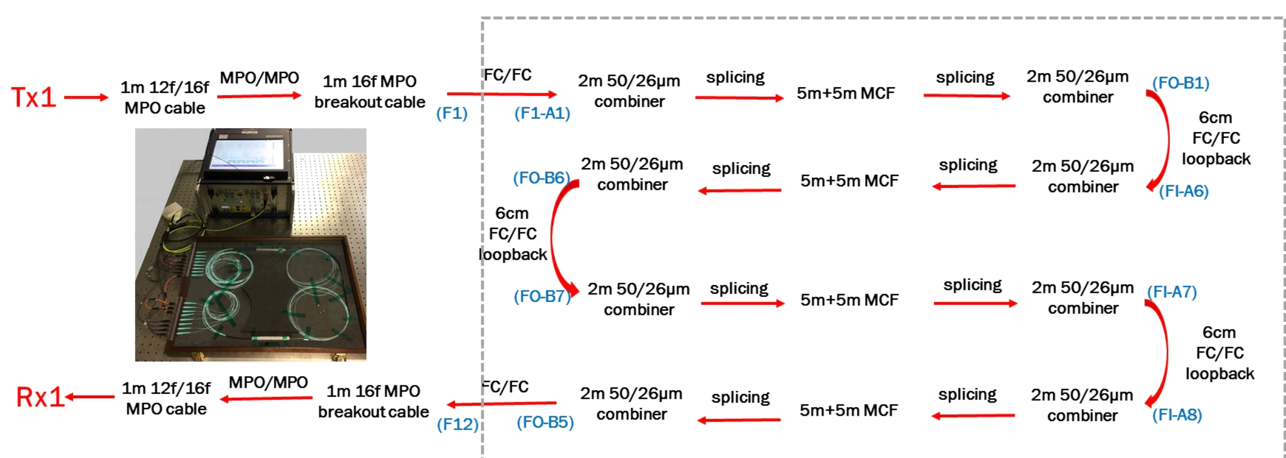


**Figure 3. Optical flow chart of the 60-meter hybrid OM4/MM-MCF link (note ports of FIFO were not all numbered in the same order, e.g., FI-A8 to FO-B5).**

of the MM-MCF and 16 meters in OM4 of the FIFO of the MM-MCF assembly. The 100 Gbps optical signals went through the cores of MM-MCF four times and multiple splices and connections including 2 MPO connections, 8 FC/FC connections, 8 FIFO to MCF splices and 4 MCF to MCF splices. The end to end attenuation of the 60 m link using the VCSEL of the transmitter under test was 3.6 dB at 850 nm and 3.8 dB at 910 nm. The other three lanes went through the cores of the MM-MCF once or in a back-to-back connection and were not at the interest of study except providing either optical or electrical crosstalk. The system transmission for 2 hours yielded neither bit error nor frame loss. The pre-FEC BER was $5.0 \times 10^{-6}$ for the 60 m link, more than 40 times better than the KP4 FEC threshold of $2.4 \times 10^{-4}$ indicating a robust system performance. Same as for the 32 m transmission described in section 3.2, no un-correctable FEC errors detected and 9 out of 15 symbols did not even show correctable errors. The robustness of the system performance was also confirmed by the 2.1 dB and 2.5 dB margins at 850 and 910 nm, measured by sweeping a VOA at the receiving end of the link.

## 4. Conclusions

In conclusions, we demonstrated a single 8-core MM-MCF supporting aggregated 800 Gbps speed over 18 m using two 400GBASE-SR4.2 transceivers. Enough system margin and pre-FEC BER 3 to 4 orders of magnitude better than KP4 FEC threshold were observed. The reach of 100 Gbps per lane was shown extendable to 32 m and 60 m by looping optical signals back to multiple cores through concatenating the output/input ports of fan-out/fan-in. Thus, we demonstrated the feasibility of the 8-core MM-MCF supporting 800 Gbps ethernet transmission suitable for short reach interconnects in data center. The loopback in the link configuration demonstrated robustness to added loss and potential cross-talk of multiple splices and FIFO transmission.

Acknowledgement: We acknowledge assistance from Viavi Solutions and FOIT.

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